The effect of glazing on the biaxial flexural strength of different zirconia core materials

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Abstract: The aim of this study was to evaluate the effect of glazing on biaxial flexural strength of different zirconia core materials. Disc-shaped zirconia (ZirkonZahn, Cercon, Ceramill) specimens (15 mm x 1.15+/-0.02 mm) were prepared according to manufacturers' instructions. The specimens from each system were divided into 2 groups (N= 10): unglazed and glazed. Glaze liquid was applied on the entire surface of the specimens of the glazed group and fired according to manufacturers' instructions. Flexural strength test was performed in a universal testing machine (crosshead speed: 1 mm/min). Data were statistically analyzed using two-way ANOVA and Tukey's test (p= 0.05). The mean flexural strength values for unglazed ZirkonZahn specimens (1388+132 MPa) were significantly higher than those of unglazed Cercon (1104+124 MPa) and unglazed Ceramill (1172+127 MPa) specimens. The mean flexural strength of glazed specimens did not show any statistically significant difference. Glazing decreased the flexural strength results significantly for all systems (p< 0.05). Glazing decreased the flexural strength values for ZirkonZahn, Cercon and Ceramill specimens. Unglazed ZirkonZahn specimens revealed significantly higher mean flexural strength values than that ofunglazed and glazed zirconia materials tested in this study.

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THE EFFECT OF GLAZING ON THE BIAXIAL FLEXURAL STRENGTH OF DIFFERENT ZIRCONIA CORE MATERIALS

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ABSTRACT

The aim of this study was to evaluate the effect of glazing on biaxial flexural strength of different zirconia core materials.

Disc-shaped zirconia (ZirkonZahn, Cercon, Ceramill) specimens (15 mm x 1.15±0.02 mm) were prepared according to manufacturers' instructions. The specimens from each system were divided into 2 groups (N=10): unglazed and glazed. Glaze liquid was applied on the entire surface of the specimens of the glazed group and fired according to manufacturers' instructions. Flexural strength test was performed in a universal testing machine (crosshead speed: 1 mm/min). Data were statistically analyzed using two-way ANOVA and Tukey's test (p=0.05).

The mean flexural strength values for unglazed ZirkonZahn specimens (1388±132 MPa) were significantly higher than those of unglazed Cercon (1104±124 MPa) and unglazed Ceramill (1172±127 MPa) specimens. The mean flexural strength of glazed specimens did not show any statistically significant difference. Glazing decreased the flexural strength results significantly for all systems (p<0.05).

Glazing decreased the flexural strength values for ZirkonZahn, Cercon and Ceramill specimens. Unglazed ZirkonZahn specimens revealed significantly higher mean flexural strength values than that of unglazed and glazed zirconia materials tested in this study.

Keywords: flexural strength, in-ceram zirconia

EFECTO DEL GLASEADO SOBRE LA RESISTENCIA FLEXURAL BIAXIAL DE DIFERENTES TIPOS DE MATERIALES PARA NÚCLEO A BASE DE CIRCONIA

RESUMEN

El objetivo de este estudio fue evaluar el efecto del glaseado sobre la resistencia flexural biaxial de diferentes tipos de materiales para núcleo a base de circonia.

Se confeccionaron especímenes de circonia en forma de disco (15 mm x 1.15±0.02 mm) de acuerdo con las instrucciones del fabricante. Los especímenes de cada sistema fueron divididos en dos grupos (n=10): glaseados y sin glasear. El líquido glaseador fue aplicado sobre toda la superficie de los especímenes del grupo glaseado y fue cocido de acuerdo con las instrucciones del fabricante. Se llevó a cabo el ensayo de resistencia flexural en una máquina universal (velocidad de desplazamiento del cabezal: 1mm/min). Los datos fueron analizados estadísticamente por medio de ANOVA de dos vías y prueba de Tukey (p=0.05).

El valor medio de resistencia flexural para los especímenes sin glasear ZirkonZahn (1388±132 MPa) fue significativamente más elevado que los especimenes sin glasear Cercon (1104±124 MPa) y Ceramill (1172±127 MPa). El valor medio de resistencia flexural para los especimenes glaseados no mostró diferencias significativas. El glaseado disminuyó significativamente la resistencia flexural de todos los sistemas (p<0.05).

El glaseado disminuye los valores de resistencia flexural de los especímenes de ZirkonZahn, Cercon y Ceramill. Los especimenes sin glasear ZirkonZahn revelaron valores significativamente más elevados que aquellos materiales glaseados y sin glasear a base de circonia empleados en este estudio.

Palabras clave: resistencia flexural, circonia

INTRODUCTION

As natural looks and esthetics come into prominence in restorative dentistry, the clinicians and the porcelain manufacturers have started to investigate the strengthening methods for ceramic restorations. All-ceramic systems are biocompatible and provide perfect esthetics. However, they must be strong enough to be used in the oral cavity. One of the strengthening methods of all-ceramic systems is to use zirconia as the core material[1,2]. Zirconia has high strength and toughness. By means of these properties, the all-ceramic restorations that use zirconia are more reliable[3]. Because zirconia is opaque, it is veneered with porcelain to provide good esthetics[4,5]. The rough surfaces of the ceramic restorations must be smoothened to be used with optimum biocompa-

tibility[6]. Glazing is a common method applied in porcelain oven to smoothen rough surfaces[7]. Glazed porcelain is the restorative material that causes the least plaque accumulation. In addition, glazed porcelain can imitate the gloss and characterization of the natural tooth[8]. The porcelain surface can be ground with diamond burs for both esthetic and occlusal adjustments. The diamond burs cause microcracks and roughen the surfaces. The glaze layer has several desirable properties. It fills microcracks[7] and covers the porosities on the porcelain[8] and also increases the strength of the material by creating compressive stresses on the surface while cooling[9,10]. In addition, it decreases the exposure of the dental restoration to oral cavity and provides the necessary smoothness[7]. In the course of veneering and glazing, the material is subjected to firing. The effect of temperature on zirconia-based materials is an important issue for the decreased fracture resistance of the material *in vivo*.

It was shown that yttrium stabilized zirconia (Y-TZP) is not stable over time. Because of this meta-stability, zirconia is subjected to aging in the presence of water. This phenomenon is called 'low temperature degradation (LTD)'[11]. Depending on several factors, $t \rightarrow m$ phase transformation occurs. These factors are: the level of temperature, water and vapor, the particle size, the amount of micro and macro cracks in the material, the yttria content and the concentration of the stabilizing oxide. The most critical temperature range for this transformation is 200-300ºC. Transformation increases in the presence of water or vapor. Although it was shown that the effect of LTD on Y-TZP can be important only after years, it was found that heat treatment and veneering affected the mechanical properties[12]. The objective of this study was to evaluate the biaxial flexural strength of varying zirconia systems after glazing.

MATERIALS AND METHODS

Three different zirconia systems indicated for making specimens, namely ZirkonZahn system (Steger, Ahrntal, Italy), Cercon system (DeguDent GmbH, Hanau, Germany) and Ceramill system (Amann Girrbach GmbH, Koblach, Austria) were used for the experiments (Table 1).

Ten disc-shaped metallic rings with 15 mm inner diameter and 2 mm thickness were used for making composite discs. The composite discs were ground to a thickness of 1.4 mm after they were made.

Specimen preparation for ZirkonZahn

ZirkonZahn (Steger, Ahrntal, Italy) specimens were produced by a copy-milling system using pre-sintered zirconia blanks. Composite models were fixed

Table 1: The brand names, manufacturers and chemical compositions of the materials tested in the study.

Brand name	Manufacturers	Chemical Composition
ZirkonZahn	Steger, Ahrntal, Italy	ZrO_2 (+HfO_2) w%:Main component, Y_2O_3 w%:4.95~5.26,Al_2O_3 w%:0.15~0.35 SiO_2 w:Max. 0.02, Fe_2O_3 w%:Max. 0.01, Na_2O w%:Max. 0.04
Cercon	DeguDent GmbH, Hanau, Germany	ZrO_2 (+HfO_2) w%:Main component, Y_2O_3 w%:5,Al_2O_3 + SiO_2 w: %1, HfO_2 w%:2
Ceramill	AMANNGIRRBACH GmbH, Koblach, Austria	ZrO_2 w%:Main component, Y_2O_3 w%:4-6,Al_2O_3 w%:0-1, HfO_2 w%:1-5
ZirkonZahn Glaze, ZirkonZahn ICE	Steger, Ahrntal, Italy	60-70 w% Ceramic powder and pigments
Stain Liquid		30-40 w% Glycole
Ceramco PFZ Overglaze,	Dentsply, York, PA, USA	60-70 w% Ceramic powder and pigments
Ceramco PFZ Stain & Glaze Liquid		99 w% Propylen glycol

in the holding plate of the scanning unit, scanned using a stylus and enlarged by a lever arm system (pantographic principle), and a pre-sintered zirconia blank was fixed in the holding plate of the milling unit of the system. The zirconia specimens were sintered at 1500ºC after they were made. Then the specimens were wet ground with a 10 N load to a thickness of 1.16±0.02 mm and wet polished with 600, 800, 1200 grit silicone carbide papers for 15 s using a grinding/polishing machine (Phoenix Beta Grinder/ Polisher, Buehler, Germany) at a speed of 300 rpm, respectively.

Specimen preparation for Cercon

The composite discs were fixed into the Cercon Brain unit (Degudent, Hanau, Germany) and scanned by a non-contact laser scanner. The data for the milling process were converted using complex software. Then the milling was started automatically with the pre-sintered Cercon blank fixed in place. The zirconia specimens were thereafter sintered at 1350ºC to full density in the Cercon heat furnace (Degudent, Hanau, Germany). Then the specimens were wet ground with a 10 N load to a thickness of 1.15±0.02 mm and wet polished with 600, 800, 1200 grit silicone carbide papers for 15 s. using a grinding/polishing machine (Phoenix Beta Grinder/ Polisher, Buehler, Germany) at a speed of 300 rpm, respectively.

Specimen preparation for Ceramill

Ceramill (AMANNGIRRBACH GmbH, Koblach, Austria) specimens were produced by a copy-milling system using pre-sintered blanks of zirconia as for ZirkonZahn. Composite models were duplicated by Ceramill Gel model acrylic. Then the models were fixed in the holding plate of the scanning unit and a pre-sintered zirconia blank was fixed in the holding frame of the milling unit of the system. The zirconia specimens were sintered at 1450ºC after they were made. Then the specimens were wet ground with a 10 N load to a thickness of 1.15±0.02 mm and wet polished with 600, 800, 1200 grit silicone carbide papers for 15 s using a grinding/polishing machine (Phoenix Beta Grinder/ Polisher, Buehler, Germany) at a speed of 300 rpm, respectively.

Glazing

All systems were divided into 2 groups. One of the groups was the control group, and the second group of all systems was glazed by overglaze technique (Table 2). The overglaze powders were mixed with their own glaze liquids and applied in a thin coat using a ceramic brush. All the systems were glazed as recommended by their manufacturers. For ZirkonZahn and Ceramill specimens, ZirkonZahn Glaze and ZirkonZahn ICE Stain Liquid (Steger, Ahrntal, Italy) were used and for Cercon specimens Ceramco PFZ Overglaze, Ceramco PFZ Stain & Glaze Liquid (Dentsply, York, PA, USA) were applied. All glazes were handled according to manufacturers' instructions and stated firing temperatures (Table 3).

Biaxial flexural test

The flexural tests were performed in a universal testing machine (Instron, 3345, Instron Corp., Norwood, MA, USA) where the load was applied at a

Table 2: Test groups.

	Zirkonzahn	Cercon	Ceramill
Control	Unglazed	Unglazed	Unglazed
Glazed	ZirkonZahn Glaze, ZirkonZahn ICE Stain Liquid	Ceramco PFZ Overglaze, Ceramco PFZ Stain & Glaze Liquid	ZirkonZahn Glaze, ZirkonZahn ICE Stain Liquid

Table 3: Firing temperatures.

	Idle	Dry	High Temperature	High Temperature Hold	Heat Rate ºC/min	Vacuum
Brand name ZirkonZahn and Ceramill	350°C	5 sec	820°C	2 min	55°C/min	+
Cercon	450°C	5 sec	850°C	30 sec	60°C/min	-

constant speed of 1 mm/min until fracture occurred. The load that led to the initial separation of specimens was obtained in Newton (N) and converted to MPa using the following equation, according to ISO 6872[13]:

$$S = -0.2387P(X-Y)/d^2$$

where 'S' was the maximum centre tensile stress (MPa), '*P*' was the total load causing fracture (N);

$$X = (1+\nu)\ln(r_2/r_3)^2+[(1-\nu)/2](r_2/r_3)^2$$

$$Y = (1+\nu)[1+\ln(r_1/r_3)^2]+(1-\nu)(r_1/r_3)^2$$

(ν): Poisson ratio;

r_1: radius of support circle (mm);

r_2: radius of loaded area (mm);

r_3: radius of specimen (mm);

d: specimen thickness at fracture origin (mm).

Statistical analysis

Statistical analysis was performed using SPSS System 15.0 for Windows. The means of each group were analyzed by two-way analysis of variance (ANOVA), with biaxial flexural strength test as the dependent variable and the zirconia systems and glazing as the independent factors. *P* values less than 0.05 were considered to be statistically significant in all tests. Multiple comparisons were made by Tukey's adjustment test.

RESULTS

There was a statistically significant difference (p= 0.011) between unglazed ZirkonZahn, Ceramill and Cercon specimens. According to Tukey's test, unglazed ZirkonZahn specimens had statistically higher flexural strength than those of Cercon and Ceramill specimens (p= 0.011, p= 0.049), whereas there was no statistically significant difference between the flexural strength of Cercon and Ceramill specimens (Fig. 1).

The results of two-way analysis of variance (ANOVA) for the experimental conditions are presented in Table 4. ANOVA showed significant influence of glazing (p<0.05). Glazing caused a statistically significant decrease in the biaxial flexural strength of all specimens tested in this study (Fig. 2). However, there was no statistically significant difference between the flexural strength of glazed ZirkonZahn, Cercon and Ceramill specimens (Table 5).

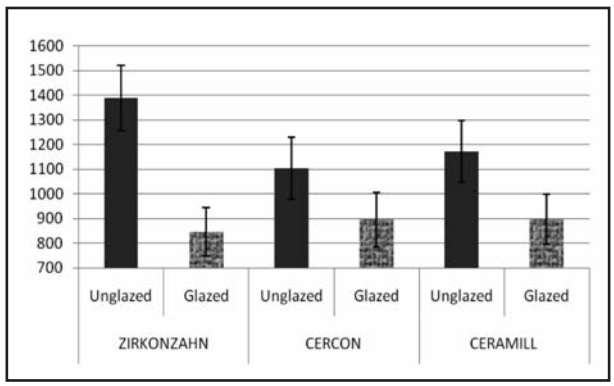

Fig. 1: The mean biaxial flexural strength values (MPa) for zirconia systems with and without glazing.

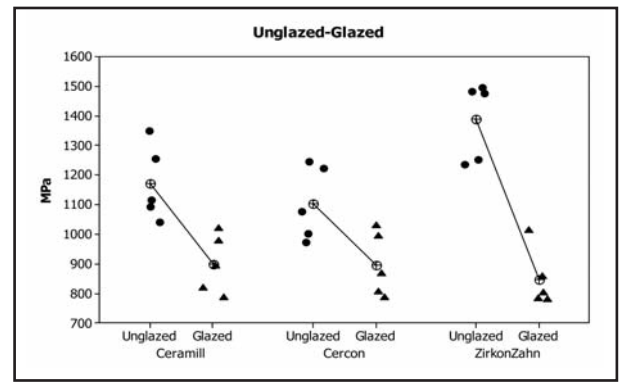

Fig. 2: Dot plot figure demonstrating the distribution of unglazed and glazed values around the mean value.

Table 4: Results of two-way analysis of variance for the experimental conditions (*p<0.05).

Source of variation	Sum of squares	Degrees of freedom	Mean ratio square	F	*p*
Glazing	875060	1	875060	65.06	0.000*
Zirconia	72422	2	36211	2.69	0.088
Zirconia x Glazing	156847	2	78424	5.83	0.009*
Error	322809	24	13450		
Total	**1427139**	**29**			

Table 5: Mean flexural strength values and standard deviations (SD) in MPa (*p<0.05).

	ZirkonZahn (MPa) (SD)	Cercon (MPa) (SD)	Ceramill (MPa) (SD)	F	*p*
Unglazed	1388 (32)	1104 (124)	1172 (127)	6.8	0.011*
Glazed	846 (98)	896 (110)	897 (100)	0.4	0.67
F	54.35	7.85	14.42		
P	**0.000***	**0.023***	**0.005***		

DISCUSSION

Glazing after grinding is believed to increase the strength because it decreases the depth of the cracks on the surface[14]. However, the strengthening effect of glazing on porcelain is not clear[14,15].

Many studies showed that glazing does not increase the biaxial flexural strength[14,16-18]. It was shown that auto-glazing did not cause a difference in the flexural strength of porcelain specimens[16-18]. Similarly, the firing of porcelain after occlusal adjustments does not increase the flexural strength either. However, glazing can be performed to create a smooth surface to prevent plaque accumulation.[17] Moreover, glazing reduces the wear of opposing enamel. It was found that glazing caused cracks in the porcelain and thus decreased the flexural strength[14].

There are other studies[15,19] showing different results on the effect of glaze on porcelain strength. It was shown that the flexural strength of glazed porcelain was higher than that of unglazed porcelain[19]. In a study that focused on the effect of auto-glazing for different durations on the fracture toughness and Vickers microhardness of the porcelain specimens[15], it was reported that as the duration of glaze firing increased the thickness of the glaze layer, the fracture toughness and the Vickers hardness increased. In a study by Brackett et al.[20], authors investigated the effect of auto-glaze, overglaze and auto-glaze with polishing on the flexural strength of the porcelain. They found out that overglazed group showed the highest flexural strength. However, there was no control group in their study. Anusavice[10] reported that when the glaze was ground from the porcelain surface, the flexural strength of the porcelain was 40-46% less than the initial strength.

In our study, to investigate the effect of glaze firing on the biaxial flexural strength of three different zirconia systems, ZirkonZahn, Cercon and Ceramill were used. Glazes were applied according to the manufacturers' recommendations for each system. It was reported that 0.05 mm thickness of glaze is enough to prolong its integrity[10]. Therefore, 0.05 mm thickness of glaze was applied to each surface (a total of 0.1 mm) of the disc-shaped specimens.

There have been different reports on the flexural strength of Cercon. In one study[21], it was reported to be 1141 (±121) MPa. In another study[22], this value was found to be 911 (±95) MPa. The flexural strength of Lava was reported as 1000 MPa[23]. In our study, the flexural strength of Cercon, ZirkonZahn and Ceramill was found to be 1104 (±124) MPa, 1388 (±132) MPa and 1172 (±127) MPa, respectively.

Some researchers[12,24] showed that keeping Y-TZP at 900ºC for 1 hour or at 900-1000ºC for 1 minute causes reverse transformation (also referred as *m→t* transformation). This phenomenon occurs with the reduction of the compressive stresses on the surface and the consequent decrease in strength. Therefore veneer firing, which is applied during production of dental restorations, can induce reverse transformation[11,24]. In another study[11], it was shown that m and t phases existed before sintering zirconia specimens at 1500ºC whereas only t phase was seen after sintering[25]. It was reported that heat treatment at 800-950ºC caused a decrease in the m content and the flexural strength (Y-TZP 897 MPa→714 MPa, NANOZR 1351 MPa→1087 MPa). It was shown that the flexural strength of DC-Zirkon (1503 MPa) decreased after a heat treatment of 820ºC (1194 MPa). According to the authors[26], this decrease in strength may be due to phase transformation of Y-TZP when subjected to stresses. In a study that investigated the effect of heat treatment on the flexural strength of Vita YZ (Y-TZP, Vita In-Ceram 2000YZ Cubes) and Denzir-M (Mg-PSZ, Denzir)[27], the authors found that heat treatment decreased the flexural strength of Denzir-M while it did not affect the flexural strength of Vita YZ. The specimens were not ground in that study. In another study[12], it was reported that the flexural strength of heat treated Y-TZP (Denzir, Cad.esthetics) specimens decreased after heat treatment. The temperatures and durations used in their experiments were: (1000ºC, 10 min), (930ºC, 1 min), (920ºC, 1min), (910ºC, 1 min),

(755ºC, 1 min), (755ºC, 2 min), (700ºC, 1 min), (725ºC, 1 min), (725ºC, 1-2 min). In the same study, it was emphasized that as the temperature rose, flexural strength decreased. One possible explanation is that the manufacturing processes may develop compressive stresses on the surface, which may in turn be relieved by heat treatment and veneering. The other probable explanations may be that *m→t* transformation and/or the change in particle size during heat treatment or veneering may cause this phenomenon.

Similarly, in our study, heat treatment caused a statistically significant decrease in the flexural strength of ZirkonZahn, Cercon and Ceramill specimens. ZirkonZahn glaze was applied at 820ºC for 2 min and Ceramco glaze was fired at 850ºC for 30 s. We assume that reverse transformation and/or change in the particle size may have occurred and/or the residual stress layer, which is formed during manufacturing processes, may have been removed from the surface with the heat treatment.

When pre-sintered Y-TZP is used for dental restorations, it is subjected to final sintering at a temperature of 1350-1550ºC according to the manufacturers' instructions. This wide temperature range affects the size of the particles and thus phase stability. As sintering temperature and time increase, the particle size increases[28]. The mechanical properties of Y-TZP depend on the particle size. There is a critical size above which the stability of Y-TZP decreases and becomes more sensitive to *t→m* transformation. In the presence of smaller particles (<1 μm), the transformation ratio decreases. Moreover, below a specific particle size (~0.2 μm), transformation is impossible; this reduces the fracture toughness. Finally, because sintering conditions affect the particle size, they affect the stability and mechanical properties of the final product. Final sintering of pre-sintered Y-TZP prevents *t→m* transformation, which is induced by stress. In addition, if grinding and sandblasting are not applied, a surface without a monoclinic phase forms. Even though transformation increases strength, most of the Y-TZP manufacturers do not recommend grinding and sandblasting in order to prevent surface cracks and *t→m* transformation[24].

Hjerppe et al.[29] investigated the flexural strength of ZirkonZahn after sintering at 1500ºC for different durations. They reported that sintering for different times did not affect flexural strength. Chevalier et al.[28] examined the probable detrimental effect of cubic phase during the sintering of Y-TZP. The authors sintered pure zirconia specimens at 1450ºC for 2 and 5 h, at 1550ºC for 2 and 5 h. They found that the particle size was very small and homogenous in the specimens sintered at 1450ºC for 2 h. The particle sizes were larger but homogenous in the specimens sintered at 1450ºC for 5 h and at 1550ºC for 2 h and a few large particles (~1 μm) were observed. In the specimens sintered at 1550ºC for 5 h, with the 2 μm particles, the structure was heterogeneous. Ruiz and Readey[30] showed the presence of cubic phase above 1500ºC. According to the phase diagram presented in another study[31], these particles contain more yttria than tetragonal particles. It was reported that while cubic particles include more yttria, the tetragonal particles around them include less yttria. It was emphasized that the cubic particles pull yttria from the tetragonal particles. As the amount of cubic particles increases, the phase transformation ratio increases as well. The sintering of Y-TZP should be carried out at a temperature low enough to prevent the dual cubic-tetragonal phase formation and high enough to achieve a full density material. This means that a narrow temperature range between 1400-1450ºC should be selected[28]. In our study, the greatest decrease in flexural strength after glazing was in the ZirkonZahn group. One possible cause is that the ZirkonZahn specimens were sintered at 1500ºC whereas the Cercon and the Ceramill specimens were sintered at 1350ºC and 1450ºC, respectively.

The tetragonal particles transform into monoclinic ones under external stresses such as grinding and sandblasting. The effect of grinding on the biaxial flexural strength depends on the volume of the transformed zirconia. This is due to the stability of t phase and the local temperature. Grinding is recommended for zirconia because it causes compressive stresses on the surface. It was shown that for *t→m* transformation hand grinding is more effective than lapper machine grinding. This is because during lapper machine grinding, the local temperature increase (above 700ºC) exceeds the *t→m* transformation temperature and causes reverse *m→t* transformation. The deep defects caused by grinding cannot be prevented by the compressive stresses formed by transformation and they reduce the flexural strength[32,33]. The most important consequence of lapper machine grinding is roughness and residual stress[33].

Kosmač et al.[34] reported that grinding reduces the monoclinic content of zirconia specimens. They found that grinding reduced the flexural strength of fine grained zirconia but did not affect the flexural strength of

coarse grained zirconia. The authors emphasized that tens of microns of material are removed from the surface during grinding and that sparkling is observed during this treatment. We also observed sparks while grinding the zirconia specimens with coarse grit abrasive. This shows the magnitude of the stress and the magnitude of the temperature achieved.

The microcracks formed after grinding and milling can progress into the material because of the change in the borders of the particles and in the particle size during heating. Heat treatment can alter the shapes of the porosities and facilitate crack propagation. It is suggested that the transformation capacity, which prevents crack formation, can be reduced by heat treatment[26].

It was shown that heat treatment after grinding lowered flexural strength[35]. In a study that investigated the effect of surface and heat treatments on the strength of DC-Zirkon[32], it was reported that heat treatment (at 930ºC for 1 min and at 910ºC for 1 min) after surface modifications (sandblasting, polishing, grinding) reduced the flexural strength of the material. The authors emphasized that heat treatment caused reverse transformation and reduced the m content. Same authors[36] discovered that when similar treatments are applied to In-Ceram Zirconia (glass infiltrated alumina/zirconia) the flexural strength increased. They reported that the effect of surface and heat treatments on flexural strength is due to a combined reaction of all phases (alumina, zirconia and glass) of the material. Moreover, the incompatibility of the thermal expansion coefficients of glass, alumina and zirconia causes compressive stresses on the surface. This may have an important role in increasing flexural strength.

Kosmač et al.[37] investigated the correlation between flexural strength and the monoclinic content after surface and heat treatments. They reported that above 350ºC, the m content of the sandblasted specimens started to decrease and above 900ºC, the m content decreased to below 2%. In addition, flexural strength decreased after heat treatment at 900ºC. It was found that grinding with coarse grit caused more decrease in flexural strength than grinding with fine grit. The authors recommend sandblasting after grinding because grinding and sandblasting have reverse effects on the biaxial flexural strength. In a study by Xu et al.[38], it was reported that when Y-TZP was ground with 25 μm grit diamond discs, flexural strength increased. On the other hand, with coarse grit grinding, flexural strength decreased. However, Xu et al. did not report the correlation between strength and monoclinic content after surface modifications. Curtis et al.[39] found that while grinding with coarse grit burs decreased flexural strength, grinding with fine grit burs did not cause a statistically significant change in the biaxial flexural strength of zirconia specimens. We believe that the grinding/polishing paper size might affect the results. Kosmač et al.[40] reported that after sandblasting, 14-15% m content was seen. In contrast, almost no m content was seen when the specimens were annealed at 920ºC after sandblasting. This shows that heat treatment caused reverse $m \rightarrow t$ transformation. The authors found that after grinding, less than 5% m content was seen and flexural strength decreased Another study[41] reported that heat treatment (500-1200ºC) after sandblasting reduced flexural strength. Micro cracks that occur during grinding and polishing and manufacturing processes may lead to deep internal stresses under 20 μm[42]. The grinding and polishing procedures we applied might have affected flexural strength. Also, during glazing, the specimens are subjected to moisture, which might have affected flexural strength[12]. The reduction in flexural strength after glazing may be due to moisture and a combination of manufacturing, grinding, polishing and heat treatment processes.

The testing of the discs by biaxial flexure does not represent a clinically relevant condition since the discs are not supported by simulated dentin or support material. Further research should consider these aspects.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. Glazing decreased the biaxial flexural strength of the zirconia materials tested.
2. Unglazed ZirkonZahn specimens had statistically higher flexural strength than those of Cercon and Ceramill specimens.
3. There was no statistically significant difference between the flexural strength of glazed zirconia specimens.

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